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DETERMINATION OF THE OPTIMAL DRIVE POWER OF A BELT VACUUM PRESS WHEN MOLDING CERAMIC PASTES

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Computational relations for determining the optimal power, taking account of the factors that affect the power and capacity of presses for molding clayey materials, are presented. Coefficients of resistance to friction as a function of the clay plasticity and category are presented.

Key words: molding, power, belt vacuum-press, pressing, extrusion die, blade, plasticity, friction, perforation.

The capacity of presses and the power which they consume depend on many factors, the main ones being the construction and dimensions of the press and the state of the working organs of the press (extruder screw, case, head, and extrusion die), the characteristic and quality of the preparation of the molded paste, the form and cross section of the article, the area of the ring gap at the entrance to the vacuum chamber or cross-sectional area of the perforated grid, and the rotational frequency of the extrusion screw and the clay mixer.

Decreasing the ring gap at the entrance into the vacuum chamber decreases the capacity of the press and increases the power consumed. Thus, as the diameter of the regulating ring on belt vacuum presses decreases from 400 to 350 mm, the capacity of the press decreases by 10 – 13% and the power consumed increases by 9 – 10% [1].

Therefore the area of the ring gap should make it possible to maintain the required degree of rarefaction in the vacuum chamber. Special cutting devices are used to obtain the best evacuation; these devices ensure that thin lobes of paste, 0.1 mm thick or a thin “noodles”, are fed into the vacuum chamber [2].

As the number of turns of the extrusion screw increases from 20 to 25 min^{-1} the capacity with moisture content 18 – 20% increases by 3.84, 3.17, and 6.25% (Table 1) [3], respectively, and the specific power consumption increases by 3 – 10%.

The power consumed by the press is expended on overcoming friction forces between the extrusion screw and the paste, on pressing the paste, and on pushing the paste through the head and extrusion die.

In addition, in vacuum presses combined with a clay mixer power is expended on compressing the paste by the feeding screw, pushing the paste through the ring, and mixing the paste in the clay mixer, and in presses which are not combined on pushing the paste through the grid.

Investigations established that the power consumed by vacuum presses minus the power consumed by the mixer and taking account of the power consumed by the vacuum pump is approximately 2.1 – 2.6 times greater than in presses with no vacuum chamber and no mixer; in addition, a great deal of value is attached to presses with extrusion press diameter 300 mm and less value is attached to extrusion screw diameter 550 mm [1].

The effect of the moisture content of the molded paste on the power and capacity of a press was checked by testing SMK-325 and SMK-133 presses at the Slavic “Armaturno-isolyatornyi zavod” JSC. It was determined that increasing the moisture content of the molded paste by 1% in the interval 18 – 21% (with constant power consumption) increases the vacuum-press capacity by 7 – 14% and decreases the specific power consumption (on 1000 conventional bricks) by 7 – 12% depending on the form of the molded article.

An excessive increase of the rotational frequency of the extrusion screw is also undesirable because the wear of its turns increases and the reverse flow of the paste in the gap between the extrusion screw and the casing jacket increases, causing the paste to overheat and the quality of the molded articles to degrade.

As a result of the effect of all factors indicated the power consumed by belt vacuum presses in different plants fluctuates over wide limits.

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In the case of presses which have a substantially lower drive power than, for example, SMK-168, the possibility of working on thin and low-moisture pastes is diminished.

Up to 90% of the power consumed by the press is expended on the main operation of the press (folding-kneading and mixing the paste) and 10% on forming blanks.

When making new designs of a new belt augur vacuum press [3], all influential actors should studied and the best (optimal) combination should be chosen on the basis of the task a hand. In so doing the minimum possible values of the rotational frequencies of the screw and the diameter of the extruding blade should be obtained, since this will give the minimum power consumption by the press.

The total drive power of modern vacuum presses in an aggregated implementation is 440 kW.

The power of a combined belt vacuum press N (W) is expended on the bottom pressing part of the press and the top mixing part which also feeds the clay paste into the vacuum chamber (by the mixer) [4]:

$$N = N_s + N_m, \tag{1}$$

where N_s is the power expended by the pressing screw, W; N_m is the power expended by the mixer, W.

The power expended by the pressing auger N_a (W) is determined from the relation

$$N_a = \frac{1}{\eta_s}(N_f + N_1 + N_2 + N_3), \tag{2}$$

where N_f is the power required to overcome the friction of the extruding blade of the screw on the clay paste, W; N_1 is the power expended to push paste through the head and extrusion die, W; N_2 is the power expended on transporting the clay paste from the receiving part of the pressing screw to the extrusion blade, W; N_3 is the power expended on compacting the paste in the head and the extrusion die of the press, W; and, η_s is the efficiency of the reducing gear of the screw.

The power consumed by the mixer N_m (W) is calculated as follows [4]:

$$N_m = \frac{1}{\eta_c}(N_t + N_{cut} + N_{c.s}), \tag{3}$$

where η_c is the efficiency of the mixer; N_t is the power expended on transporting the clay paste by the mixer blades, W; N_{cut} is the power expended on cutting the clay paste by the mixer blades, W; $N_{c.s}$ is the power consumed by the conical extrusion screw (Fig. 1) of the mixer, W.

Aside from the power consumption mentioned above, it is also necessary to take account of the power consumed by the cutting devices, which permit feeding the clay paste into the vacuum chamber; the power consumed by the feeding rollers or blades and other mechanisms which make press operation possible.

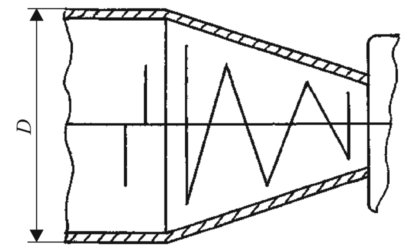

Fig. 1. Conical extrusion screw of the mixer.

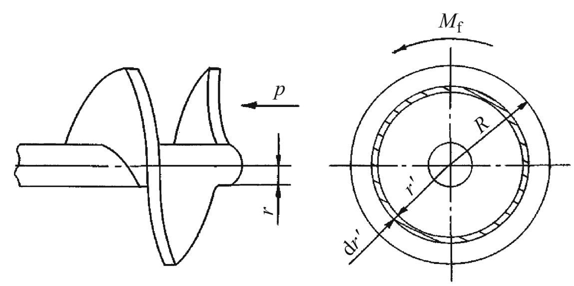

Fig. 2. Diagram for determining the power expended on friction.

We shall now examine the main relations for calculating the power of the main drive of the press, which appear in the relations (2) and (3).

The power N_f (W) consumed to overcome the friction of the extrusion blade of the screw against the clay paste is determined by the relation [4]

$$N_f = M_f n_{opt.s}, \tag{4}$$

where M_f is the friction moment, N · m; $n_{opt.s}$ is the rotational frequency of the screw, sec^{-1}.

The following elementary pressure force acts on an elementary ring-shaped area (Fig. 2) with radius r' and width dr':

$$dP = p\,2\pi r'\,dr', \tag{5}$$

where p is the specific pressing pressure, Pa, determined by the relation of [5].

The elementary friction force is

$$dT = f dP = fp\,2\pi r'\,dr', \tag{6}$$

where f is the coefficient of friction of the clay paste against the surface of the screw blade.

The friction coefficient depends on the plasticity of the paste (with the same rate of working of the screw surface approximately with class 7 roughness). Under real design conditions the friction coefficient is determined experimentally.

Ordinarily, the friction coefficient for highly plastic clay plasticity is $f = 0.35$ for category 1 pastes; $f = 0.40$ for category 2 pastes; and, for $f = 0.45$ category 3 pastes.

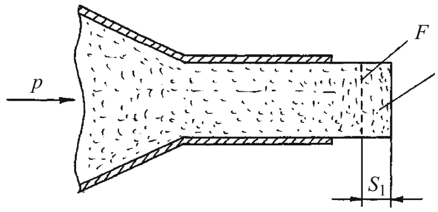

Fig. 3. Diagram for determining the power expended on extruding the paste.

The elementary friction moment is

$$dM_f = r dT, \tag{7}$$

and the total friction moment is

$$M_f = fp\, 2\pi \int_r^R r'^2 dr'. \tag{8}$$

Transformation of the equations gives

$$M_f = fp\, 2\pi \frac{R^3 - r^3}{3}. \tag{9}$$

Then the power expended on friction is

$$N_f = 6.28 \times 2\pi fp \left(\frac{R^3 - r^3}{3}\right) n_{opt.s}, \tag{10}$$

or

$$N_f = 13.2 fp\,(R^3 - r^3) n_{opt.s}. \tag{11}$$

The power N_1 (W) expended on pushing the clay paste through the head and extrusion die of the press, equal to the work A_1 (J) performed per unit time, is

$$N_1 = A_1/t. \tag{12}$$

The work is determined as the product of the extrusion force along the path S_1 (Fig. 3) traversed by the clay paste (bar) over one revolution of the screw is

$$A_1 = pFS_1, \tag{13}$$

where p is the specific pressing pressure, Pa; F is the cross-sectional area of the die (bar), m^2.

The product FS_1 is the volume V_1 (m^3) of the bar extruded over one turn of the screw.

This "unit" volume can be expressed in terms of the press capacity Q and the rotational frequency of the screw:

$$V_1 = Q/n_{opt.s}. \tag{14}$$

Substituting this expression into the relations (13) and (12) we obtain

$$N_1 = pQ/n_{opt.s}. \tag{15}$$

The power N_2 (W) expended on transporting paste from the receiving part to the extrusion blade of the screw (this is the work of transport) can be expressed as

$$N_2 = Q\rho Lkg, \tag{16}$$

where ρ is the density of the clay mass moved, kg/m^3; L is the path of motion (length of the screw), m; k is the coefficient of resistance to friction of the clay paste against the ribbed surface of the jacket of the cylinder of the press and depends mainly on the plasticity of the clay paste. On the basis of the experimental data [4] it can be assumed that $k = 4$ for category 1 high-plasticity pastes; pastes $k = 4.75$ for category 2 pastes; $k = 5.5$ for category 3 pastes; and, g is the acceleration of gravity, m/sec^2.

The power N_3 (W) expended on compaction of the clay paste is calculated as

$$N_3 = A_{pr} n_{opt.s}. \tag{17}$$

where A_{pr} is the work of pressing, J; $n_{opt.s}$ is the rotational frequency of the extrusion screw, sec^{-1}.

The volume decreases in this process. In turn, the work of pressing can be expressed as

$$A_{pr} = \sigma a V, \tag{18}$$

where σ is the volume compression stress, Pa; a is a coefficient that characterizes the decrease of the volume of the pressed paste, whose magnitude depends on the pressing pressure p (for clay paste $a \approx 0.250$); V is the volume of the pressed paste, m^3, given by

$$V = \frac{\pi D^3}{4} S,$$

where D is the diameter of the extrusion blade of the screw, m, and S is the step of the extrusion blade of the screw, m.

Since during pressing the paste is under hydrostatic compression and has no possibility of moving laterally the compression stress σ (Pa) is given by

$$\sigma = \frac{P(1+2\xi)}{3}, \tag{19}$$

where ξ is the coefficient of lateral pressure.

Experiments show that $\xi = 0.74$ for high-plasticity pastes; $\xi = 0.72$ for medium-plasticity pastes; and, $\xi = 0.70$ for low-plasticity pastes.

When molding hollow articles the power increases, since the pressing pressure increases by 15 – 17%.

In summary, the computational relations for determining the power expended by the main part of the belt vacuum press make it possible to determine the optimal power for the press as a function of the physical-chemical properties of pastes and other factors listed above.

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